This is an electronic version of the U.S. Coast Guard Commandant Publication "Omega Navigation System User's Guide" (COMDTPUB P16566.3). It contains text only. Users should be aware that this material does not contain all of the charts, diagrams, and figures which the text may refer to. For a complete, printed copy of the User's Guide, please send your request to the address listed below (ATTENTION OPS).

INTRODUCTION

The purpose of this booklet is to provide general information about the Omega navigation system and to present an introduction to the basic theory of Omega navigation. There is a very wide range of uses of Omega and types of equipment. Omega receivers vary from simple single frequency manual receivers to fully automatic multiple frequency receivers integrated with other onboard navigation sensors. Use of Omega has expanded from traditional marine and air navigation to include land navigation, research, and time/frequency dissemination applications. Because of this wide variety of uses and equipment, a complete, detailed description of Omega use is beyond the scope of this booklet. Standard air and marine navigation texts should be consulted for a more detailed theory of navigation using Omega, and users of Omega equipment should be sure they are completely familiar with the technical manuals for their receivers before using them for navigation. Navigators are cautioned never to place total reliance on any single aid to navigation or position fix. Positions should always be compared with dead reckoning plots or intended waypoints and checked with other available aids to navigation. Particular caution must be exercised when inserting waypoints in automatic navigation systems.

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CHAPTER 1. THE OMEGA NAVIGATION SYSTEM

A. GENERAL DESCRIPTION: Omega is a worldwide, internationally operated, ground based radionavigation system, operating in the very low frequency (VLF) band between 10 and 14 kilohertz (kHz). Its purpose is to provide a continuous, medium accuracy aid to navigation intended primarily for air and marine enroute oceanic navigation and domestic enroute air navigation. The nominal fix accuracy of Omega is two to four nautical miles (n.mi.). While not specifically intended for land navigation or non navigation purposes, Omega is being used in a number of terrestrial navigation/location and time/frequency dissemination applications. The Omega system consists of eight widely separated transmitting stations which emit continuous wave VLF signals. An Omega receiver determines position by making range measurements based on the phase of the received signals from two or more Omega stations or by making phase comparisons between signals of selected pairs of Omega stations, which produces intersecting lines of position.

Omega grew out of research into long range electronic navigation systems which took place during and after World War II. Operational Omega stations began broadcasting navigation signals in the mid 1970's, and the system reached its final eight station configuration in 1982. Omega, the last letter of the Greek alphabet, was chosen as the name of the system because in its early development in the 1950's it was thought that 10 kHz was the lower end of the usable radio spectrum.

B. TRANSMITTING SYSTEM: The eight Omega transmitting stations are listed in Table 1.Each transmitting station is identified by a letter from A through H. Omega is operated as an international partnership between the United States and Argentina, Australia, Liberia, France, Japan and Norway. Each station is staffed and operated by the nation in which it is located. The Japanese Maritime Safety Agency is responsible for synchronization of the transmitted signals of all stations. The U.S. Coast Guard, through the Navigation System Center (NAVCEN), has operational control of the system and is responsible for electronics engineering and logistics support of the transmitters. Overall coordination of operations and policy is governed by the International Omega Technical Commission, which is composed of one member from each of the nations which operate Omega stations.

C. SIGNAL FORMAT: Each Omega station transmits continuous wave, unmodulated radio frequency signals on 10.2 kHz, 11.05 kHz, 11-1/3 kHz, and 13.6 kHz. In addition to these frequencies, common to all stations, each station transmits a unique frequency, as listed in Table 2. Transmissions are sequenced in the format shown in Figure 1, so that no two stations are transmitting the same frequency at the same time, and there is no overlap of transmissions. Each transmission segment is between 0.9 and 1.2 seconds long, with a 0.2 second silent interval between each segment. The complete format contains eight transmission segments. The duration from the beginning of the first segment to the end of the silent interval following the last segment is ten seconds. This format is repeated continuously by all stations.

Each station's transmissions are synchronized to within +/-2 microseconds of the mean EPOCH, or reference time, of all eight stations. The mean epoch of the system, Omega system time, is synchronized to within 95 microseconds of Coordinated Universal Time (UTC). Omega system time is referenced to UTC as follows: At the beginning of every third signal format, which occurs at seconds 00 and 30 of Omega system time, the amplitude of the signal at each antenna is zero and increasing in a positive direction. At 00h 00m 00s UTC on January 1, 1972 this epoch was coincident with UTC, i.e., Omega system time was also 00h 00m 00s. Periodically a "leap second" is inserted in UTC to account for variances in the earth's rate of rotation. Since Omega epoch is held constant when leap seconds are inserted, there is a growing offset between Omega system time and UTC. This offset is an integral number of seconds and does not affect the synchronization of Omega system time with UTC. As of the leap second insertion on December 31, 1995, Omega epoch LEADS UTC by twenty seconds. Most navigators need not be concerned about the offset between Omega system time and UTC. This is usually accounted for in the receiver design. Refer to your owner's manual for specific information.

A. PHASE MEASUREMENTS: Navigation with Omega is possible because of the long wavelength, long range and stability of Omega signals. The underlying principle of Omega is the ability to measure the phase of the Omega radio wave, which allows position determination by either of two principal methods. In the direct ranging, or rho rho mode, phase measurements of signals from several individual Omega stations will give the range from each station. The Omega receiver computes a position based on these ranges. In the hyperbolic mode, measuring the difference in phase between signals from two or more pairs of Omega stations gives a hyperbolic line of position (LOP) between each station pair; the intersection of two or more such LOPs gives the receiver's position.

To understand how Omega phase measurements are made, a brief review of the principle of radio waves will be helpful. An oscillating electrical current in an Omega transmitting antenna causes radio waves to radiate outward in all directions, similar to the ripples seen on the surface of a pond when a stone is thrown in. Each complete wave, or cycle, has 360 degrees of phase. 360 degrees of phase at the end of one cycle is equivalent to 0 degrees of phase at the beginning of the next cycle. This pattern is repeated endlessly as the signal travels outward from the transmitter, as shown in Figure 2. b

B. THE DIRECT RANGING MODE: Omega waves are very long. At 10.2 kHz, the primary navigation frequency, the wavelength is about 16 n.mi.. Each wavelength, or cycle, is called a lane. An Omega receiver measures the phase of the Omega wave within a known lane; the range from the transmitter is equal to the number of whole lanes plus the fractional lane distance indicated by the phase measurement. In the diagram shown in Figure 2 the circular lane boundaries appear to be formed by stationary wave fronts, or rings of zero phase. If this was the case, it would be a simple matter to make direct measurements of phase, and hence range, within any lane. It must be kept in mind, though, that the waves are travelling away from the transmitter at the speed of light. An Omega receiver must be designed in a way to "freeze" the wave for an instant in order to make a phase measurement.

This is done through the use of an oscillator in the receiver which generates a reference frequency identical to the transmitted Omega frequency. When the receiver is turned on and initialized at a known position, the internal reference frequency is synchronized in time and phase with the received signal so that the beginning of the reference and received cycles is occurring at precisely the same time. This is analogous to freezing the motion of a spinning wheel with a strobe light. When the strobe light's frequency matches the wheel's frequency of rotation, the wheel appears to be stationary. Similarly, the received Omega signal appears to be a stationary train of waves. As the receiver begins to move toward or away from the transmitter, there is a phase shift between the beginning of the received signal cycle and the reference signal cycle. This phase shift indicates the distance travelled by the receiver. As each lane boundary is crossed, the receiver registers the distance travelled as the number of whole lanes plus the fractional part of a lane, indicated by the phase shift. This concept is illustrated in Figure 3. In the example in Figure 4 an Omega receiver is initialized at a known point, 1, with distances from stations A and B indicated by ranges A1 and B1, corresponding to a known number of whole lanes and fractional parts of lanes. As the receiver travels to point 2 it counts the number of lanes it passes and measures the fractional part of each present lane as a phase shift. The total number of lanes traveled plus the fractional part of each present lane gives the ranges A2 and B2, which give the position at point 2. This is how the ranging mode works. Ranging receivers are programmed to automatically apply the necessary propagation corrections (PPCs; discussed in Chapter 4) and to convert the corrected ranges into a latitude/longitude display.

C. THE HYPERBOLIC MODE: In the hyperbolic mode the receiver measures the difference in phase between pairs of transmitters, rather than directly between individual transmitters and the receiver. Figure 5 shows two Omega stations, A and B, transmitting a signal on the same frequency. The stations are synchronized so that the wave is at zero phase at both antennas at precisely the same time, and succeeding wave fronts are at equal distances from their respective sources. Since the phase is zero at each wave front, at the intersection of each wave front the phase difference between signals from transmitters A and B is zero. Connecting the intersecting wave fronts yields a series of lines of constant phase difference, called isophase contours, which take the shape of hyperbolic curves. At any point on any isophase contour the phase difference A-B will always be zero. At any point between two isophase contours there will be a difference in the phase of the two signals. This phase difference represents a fractional distance between isophase contours.

The set of isophase contours between a station pair forms a series of lanes, each corresponding to one complete cycle of phase difference. Note that in the direct ranging mode lanes are formed by concentric rings of zero phase with a constant interval of one wavelength (16 n.mi. at 10.2 kHz). In the hyperbolic mode one complete cycle of phase difference occurs every one half wavelength. Therefore 10.2 kHz hyperbolic lanes are 8 n.mi. wide on the baseline and gradually diverge as the distance from the baseline increases. Each lane, or cycle of phase, is divided into hundredths of a lane called centilanes (cel). The phase difference between station pairs, measured in hundredths of a cycle, or centicycle (cec), gives a hyperbolic line of position (LOP) within an Omega lane. (The term cel refers to the fraction of the charted lane. The term cec refers the phase measurement as a percentage of a cycle. At 10.2 kHz they are numerically equal and often used interchangeably, with cec being used most commonly.) For example, in Figure 6 phase differences of 20 cec and 50 cec between stations A and B would give LOPs as shown. 20 cec would indicate an LOP 20% of a lane width from the lane boundary and 50 cec would indicate an LOP 50% of a lane width from the lane boundary. Fractional lane widths are taken from a given lane boundary toward the direction of the station with the letter designation occurring later in the alphabet. (From the "lower" letter to the "higher" letter.) Since the same phase difference will be observed at any point on an LOP, a second LOP must be taken using another station pair. In Figure 7 the phase difference A-B is 80 cec and the phase difference B-C is 50 cec. The intersection of these LOPs gives a position fix. In actual practice PPCs would have to be applied to the observed phase difference readings before plotting; this will be discussed in Chapter 3.

D. LANE AMBIGUITY: In the above examples it is assumed that the vessel's position is known to within a particular set of lanes. Because of the cyclic nature of the phase differences, the same phase difference can be observed in any lane. This is known as lane ambiguity. On the baseline between station pairs there are about 600 10.2 kHz lanes between station pairs, 8 n.mi. wide on the baseline and diverging to about 12-15 n.mi. near the limits of coverage. The navigator has to know which of these lanes the craft is in before plotting a fix.

Lane ambiguity can be resolved by three methods. The preferred method is to set the receiver's lane count at a known location, such as the port of departure. As the vessel moves across lane boundaries the receiver will automatically update the lane identification numbers, allowing the navigator to plot fixes with phase difference measurements in a known lane. If the lane count is lost, such as due to loss of power to the receiver, the lane count must be reset based on dead reckoning, celestial fix or other electronic fix. The third alternative is to derive a coarse lane using multiple frequencies.

In our examples up to this point we have considered only 10.2 kHz. Many receivers are capable of using the other Omega frequencies for various purposes. One such purpose is lane ambiguity resolution. There is a 3:4 frequency ratio between 10.2 kHz and 13.6 kHz. This relationship also applies to their wavelengths. Three 10.2 kHz wavelengths are the same length as four 13.6 wavelengths, or 24 n.mi. on the basline in the hyperbolic mode (48 n.mi. in the direct ranging mode). A wavelength of 24 n.mi. would correspond to a frequency of 3.4 kHz, which is the difference between 10.2 and 13.6 kHz. The receiver can synthesize a 3.4 kHz Omega signal by combining the 10.2 and 13.6 kHz signals. 10.2 kHz lane numbers which are evenly divisible by three form the boundaries of 3.4 kHz coarse lanes. 3.4 kHz phase differences can be plotted in these coarse lanes. The resulting fix is then used to reset the 10.2 kHz lane count.

CHAPTER 3. NAVIGATING WITH OMEGA MORE DETAILED INFORMATION

A. USE OF MULTIPLE FREQUENCIES: The preceding chapter gave some simplified examples of how Omega works using 10.2 kHz only, with an introduction to lane ambiguity resolution using two frequencies. Referring back to the Omega transmission format in Figure 1 we see that there are four frequencies common to each station and one frequency unique to each station. 10.2 kHz is considered the primary navigational frequency since this frequency is used by virtually all Omega receivers Inexpensive single frequency receivers use 10.2 kHz only, while more sophisticated receivers use 10.2 kHz plus various combinations of the other frequencies. How other frequencies are used varies according to the design of the receiver and the intended application. Other frequencies may be used to synthesize even larger coarse lanes for lane ambiguity resolution. For example, 1.133 kHz, the difference frequency of 10.2 kHz and 11-1/3 kHz (11.333 kHz), gives a coarse hyperbolic lane width of 72 n.mi. Unique frequencies are used by some receivers for station identification when initializing the receiver.

In the simplified examples of position fixing with Omega it was assumed that the 10.2 kHz phase measurements were taken simultaneously. Since the Omega signal format is organized so that no stations transmit the same frequency at the same time, phase measurements from separate stations must actually be made several seconds apart. The receiver does this by making one phase measurement with respect to the internal oscillator, storing this reading, then making a phase measurement of another station with respect to the internal oscillator, and comparing the two readings. In the hyperbolic mode, even though the result is the phase difference between two Omega stations, the reading is still derived by making separate comparisons between the stations and the internal oscillator and differencing the two readings. In a ship moving at 20 knots a delay of a few seconds between phase readings from separate stations is inconsequential. In an aircraft travelling at several hundred knots, however, this delay between phase readings will cause serious position errors if not accounted for. Using a technique called RATE AIDING, speed and heading inputs are used by the Omega receiver to advance previous phase readings to the present position, giving the effect of simultaneous readings.

B. COMPARISON OF HYPERBOLIC AND DIRECT RANGING MODES OF OPERATION:

Each Omega station's transmissions are controlled by a bank of extremely precise cesium beam frequency standards or "atomic clocks". The stations are very closely synchronized with each other, and the Omega system is kept closely synchronized with the international time standard of UTC. In most Omega receivers the internal oscillator is much less accurate than the transmitter's atomic clock, and this must be accounted for. There will always be some offset or initial error when the receiver is turned on, and there will be some drift of the internal oscillator during the flight or voyage. When the receiver is initialized at the point of departure, the internal oscillator is synchronized in time and phase with the Omega signal format. After initialization the internal oscillator will begin to drift with respect to the Omega signal. In the hyperbolic mode the phase difference between two stations, A and B, is determined by taking the difference between the phase of station A and the internal oscillator and the phase of station B and the internal oscillator. Any error in the internal oscillator is cancelled out by this differencing method and the result is the phase difference A-B.

In the early development of Omega the hyperbolic mode was the best means available for processing the signals at a reasonable receiver cost. Some low cost receivers available today still use the hyperbolic mode with lane count and phase difference displays. Direct ranging was possible, but it required the use of a very precise oscillator, nearly equivalent instability to the transmitter's atomic clock. A receiver so equipped, once initialized at a known point, can determine position by direct ranging to as few as two Omega stations, but is very expensive. As microprocessor technology has advanced, an alternative means of direct ranging has come into common use. In this method, phase readings from three Omega stations are taken using an internal oscillator with some unknown error. The ranges to all three stations will be in error by the same amount, i.e. the amount of oscillator error, and their LOPs will not intersect at a single point. The microprocessor is able to adjust the LOPs so that they intersect at a single point, or nearly so. The amount of adjustment computed is equal to the oscillator error. In this way short term corrections to the oscillator are continuously computed by the receiver. This form of direct ranging is called the RHO RHO RHO mode, since three ranges are used, but it is often referred to simply as rho-rho. Ranging receivers are not limited to using two or three Omega stations; depending on the design, some may use phase measurements from all stations being received. Some receivers may be equipped with an optional precise oscillator, usually a rubidium frequency standard, to enhance their performance.

C. VLF AUGMENTATION: The U.S. Navy operates eight long-range very low frequency (VLF) communications stations located around the world. These stations transmit continuous wave signals between 16 kHz and 30 kHz, with frequency shift keying (FSK) or minimum shift keying (MSK) modulation. Their transmissions are controlled by cesium beam frequency standards, similar to those used at Omega stations, making their transmissions very phase stable. Because of their stability and long range, VLF communications transmissions can be used for direct ranging navigation similar to the way that Omega signals are used. Some Omega receivers are designed to use VLF communications signals to augment their position solution. Such augmentation may be particularly useful when an Omega station is off air for maintenance, reducing coverage, or the Omega signal strength or geometry is poor.

VLF communications stations have been very reliable to date, maintaining their normally assigned frequency and signal format. However, they are not intended for navigation and can change phase, frequency, format, broadcast schedule or cease transmissions with no advance notice. Accordingly, U.S. Navy VLF communications signals should be used with caution. Neither the U.S. Navy nor the U.S. Coast Guard can assume responsibility or liability for navigation errors resulting from the use of VLF communications signals.

D. DIFFERENTIAL OMEGA:

Differential Omega is a medium range accuracy enhancement technique which uses locally broadcast phase corrections to reduce Omega position errors. Omega is expected to give a nominal position fix accuracy of two to four nautical miles. Almost all of the position error in Omega is due to uncertainties in propagation over a signal path of several hundred to several thousand miles A differential Omega system employs a land based omega signal monitor at a fixed location. Since the position of the monitor is known, it is possible to predict the phase readings for each Omega signal received. Any deviation from the expected or ideal readings is due to unpredictable propagation errors. The difference between the ideal and actual readings is broadcast from the monitor as a local phase correction. The local correction is applied to the received Omega signal to improve the accuracy of the Omega position.

Differential Omega stations are normally co-located with marine radiobeacons. The differential correction is transmitted as a modulation of the radiobeacon signal. Position accuracies of a few tenths of a nautical mile may be obtained within a 50-100 n.mi. radius of the differential station. At the extreme range of the radiobeacon signal, typically about 500 n.mi., position accuracy will be about 1 n.mi.

Differential Omega stations are currently operated on the North Atlantic coasts of Europe and Africa, the western Mediterranean Sea and some parts of the Caribbean Sea and Eastern Canada. Several new stations are planned in Indonesia. The U.S. Coast Guard does not operate any differential Omega stations. Local hydrographic or aids to navigation authorities should be consulted for more information about differential Omega in a particular area.

E. PLOTTING AN OMEGA FIX: Phase difference readings from manual Omega receivers must be corrected using propagation correction (PPC) tables before they can be plotted. This is done according to the following procedure:

1. Having ensured that the proper lane count has been maintained, observe the phase difference readings for the station pairs in use.

2. For each Omega station received, select the PPC Tables for the appropriate area of the world.

3. In each PPC Table, select the quadrangle in the page index which bounds the present position. Go to the page for that quadrangle and extract the PPC for the GMT hour and date of the phase readings, noting the sign of the tabulated value. If greater accuracy is desired, follow the interpolation instructions contained in the front of each PPC Table.

4. Determine the propagation correction for each station pair by subtracting the PPC for the station whose letter designation occurs later in the alphabet from the PPC for the other station. (Subtract the PPC for the station with the "higher" letter from the PPC for the station with the "lower" letter".)

5. Apply the propagation corrections, according to their sign, to the observed phase difference readings for each station pair. Plot the corrected readings in the indicated lanes on the chart using the interpolator printed on the chart.

This procedure is illustrated in the following example: A vessel departs the Mediterranean Sea on a westerly course. The navigator selects Omega Stations A (Norway), B (Liberia), and D (North Dakota) because the coverage diagrams show good day and night signal strength and no modal interference for these stations on this leg of the voyage. The stations are paired A-B, A-D, and B-D, since these LOPs have large crossing angles. The lane count for each station pair is set at the port of departure by reading the lane numbers from the Omega chart. Passing through the Strait of Gibraltar the lane count is verified by a fix taken with visual bearings and radar ranges.

At 2000 local time on 12 May, in approximate position 36"30'N,15"30'W, the navigator records the following readings on the Omega receiver: AB 913.74, AD 802.48, and BD 788.81. The whole numbers identify the respective lanes and the numbers to the right of the decimal give the phase difference in cec. One hour is added to the local time to convert to GMT. The navigator selects PPC Tables for Stations A, B and D for Area 12, North Atlantic (Figure 10). The PPC Table page index, Figure 11, shows that PPCs for the approximate position are listed on page 76. Going to page 76 of the tables for each station, the navigator enters the table with the GMT hour and the two week period which includes the present date and extracts the corresponding PPC. The PPC for station A is -33 cec; for station B, -41 cec, and for station D, -18 cec. The corrections for each station pair are found by subtracting the respective PPCs as follows: Correction AB = PPC A - PPC B = (-33) - (-41) = +0.08 cec Correction AD = PPC A - PPC D = (-33) - (-18) = -0.15 cec Correction BD = PPC B - PPC D = (-41) - (-18) = -0.23 cec The corrections are then applied to the observed readings to obtain corrected readings:AB 913.74 + 0.08 = 913.82 AD 802.48 - 0.15 = 802.33 BD 788.81 - 0.23 = 788.58

CHAPTER 4. OMEGA SIGNAL PROPAGATION, AVAILABILITY AND COVERAGE

A. OMEGA SIGNAL PROPAGATION:

Because of the very long distances traveled by Omega signals, often several thousand miles, the effects of the propagation of the signals through the atmosphere are very important. Even though most modern receivers are designed to automatically compensate for predictable variations in propagation, an understanding of some basic principles will help you use your Omega receiver more effectively.

Omega signals radiate through the atmosphere in the region between the earth's surface and the lower part of the ionosphere. The ionosphere is a layer of electrically charged particles which bend and reflect signals along the curvature of the earth, rather than letting them travel straight out into space. This region in which the signals travel is called the WAVEGUIDE. Ideally, Omega signals would travel with uniform intensity and phase in all directions through the waveguide. However, the signal strength and phase of Omega signals are influenced by many factors, including the height of the ionosphere, which varies regularly each day and over the year; ground conductivity, the orientation of the signal path to the earth's magnetic field, and the physical behavior of the radio waves. Because of these factors Omega signals are displaced from their ideal positions and observed phase differences must be corrected to obtain accurate positions.

Omega signals are most stable and therefore most accurately predictable when the entire signal path (from transmitter to receiver) is in daylight, and slightly less stable when the signal path is in darkness. During the daytime the sun's energy causes the reflective boundary in the ionosphere to remain fairly constant at a height of about 70 kilometers (km). At night, in the absence of solar radiation, the height of the reflective boundary increases to about 90 km, causing changes in the phase of signals. Also, at night the reflective boundary becomes more diffuse, which causes greater uncertainty in signal propagation. When the sunrise/sunset line, or TERMINATOR, crosses the Omega signal path, this is known as TRANSITION. The transition of the ionosphere from its daytime to nighttime height, or vice versa, causes changes in the signal phase. In some cases these changes can be abrupt and can cause position errors due to CYCLE JUMP or LANE SLIP, where the receiver's lane count is erroneously changed due to the rapid phase shift. The more closely the signal path parallels the terminator, the more pronounced the transition effect is. The transition effect is least apparent when the signal path is at right angles to the terminator.

The rate at which Omega signals lose their strength, called the ATTENUATION RATE depends on several factors. The attenuation rate on sunlit paths is greater than on darkened paths, so signals can normally be received at greater distances at night. The attenuation rate increases as ground conductivity decreases. Seawater paths, with higher conductivity, have the least attenuation, while signals passing over tundra and freshwater ice, such as Greenland and Antarctica, have the greatest attenuation rates. The earth's magnetic field has a pronounced effect on Omega signals. Signals traveling from west to east have the lowest attenuation rate; north to south or south to north paths have a medium attenuation rate; and the attenuation rate is highest for signals travelling from east to west.

On any one frequency the Omega signal may propagate in several different MODES. Each mode propagates outward from the transmitter with a slightly different PHASE VELOCITY and hence can give different phase readings. Within a range a 450 n.mi. of the transmitter many modes may exist and interfere with each other, making Omega signals unreliable. This phenomenon is called MODAL INTERFERENCE. Within the signal coverage area, beyond 450 n.mi. from the transmitter, dominant MODE 1 signals are usable for navigation. Modal interference also occurs at long distances from the transmitter, limiting use of signals. Signal coverage diagrams, discussed in the Section C of this chapter, indicate areas of predicted modal interference. Modal interference is most prevalent at night in areas northwest and southwest of the transmitter, and is particularly severe if the northwest/southwest path crosses the GEOMAGNETIC EQUATOR. (The geomagnetic equator lies between the magnetic north and south poles. For estimating effects on Omega signals, it can be considered roughly equivalent to the geographic equator.) Modal interference is always present at the ANTIPODE of the transmitter, which is the point on the globe directly opposite the transmitter. At the antipode Omega signals are arriving from all directions with different phase values, depending on the conditions on the signal path. As the signals converge from all directions their strength increases as their energy is concentrated in an increasingly smaller part of the waveguide. This effect is called FOCUSING.

Under certain conditions Omega signals can travel completely around the world and be received from the opposite direction of the transmitter, interfering with the signal coming directly from the transmitter. This phenomenon is called LONG PATH INTERFERENCE. Long path interference is most likely to occur when the direct path is in all daylight and the long path is west to east in darkness, particularly if the ground conductivity is higher on the long path.

The propagation effects described above are predictable. Those effects which cause variances in signal phase can be mathematically modeled to produce propagation corrections (PPCs) for specific places and times. PPC's are published in a series of tables covering all areas of the world (An example of PPC Tables is shown in Chapter 3). Automatic Omega receivers have the PPCs programmed into their memory and will apply them in computing a position fix. Raw phase difference readings taken from manual receivers must be corrected with PPCs before they can be plotted on a chart, as described in the previous chapter. Areas of signal coverage and modal interference can be predicted and are displayed in coverage diagrams discussed in Section C of this chapter. Automatic receivers can be programmed to automatically deselect signals which might be disturbed by modal or long path interference.

There are also unpredictable propagation conditions of which navigators should be aware. Disturbances on the surface of the sun called solar flares emit large amounts of atomic particles and radiation which, when they reach the earth, can suddenly alter the reflective height of the ionosphere. This will cause deviations from the predicted phase values for Omega signals and introduce errors in position fixes. There are two kinds of unpredictable signal disturbances. Bursts of x-rays from the sun can cause sudden ionospheric disturbance (SID). SIDs occur only on signal paths in all or partial daylight and typically last 40-120 minutes, but in some cases can persist for up to four hours. During periods of low solar activity, SIDs may occur once or twice per week, while at other times as many as ten SIDs may occur each day. Because SIDs are so common and take place very quickly, navigational warnings are not issued when they occur.

Another type of signal disturbance is caused by streams of high energy protons from solar flares. These particles are funneled into the polar regions by the earth's magnetic field, also causing a change in the reflective height of the ionosphere. These polar cap disturbances (PCD; previously called polar cap absorption events or PCA) can cause navigational errors in receivers using signal paths which cross the polar regions above 60 degrees north or south latitude, in both daylight and darkness. PCDs occur much less frequently than SIDs, about six to ten times per year. PCDs persist much longer than SIDs, however, usually lasting several days to over a week. Navigational warnings are issued when a PCD is detected, but navigators are cautioned that detection and reporting of a PCD can can take twelve hours or more. (Streams of particles also cause aurorae or "northern lights", which may indicate a possible Omega signal disturbance.)

The effect of SIDs and PCDs on navigational accuracy depends on many factors, including the magnitude of the disturbance, the signal paths being used, the design of the receiver and the mode of operation. Position errors of four to eight nautical miles may commonly occur, but much larger errors are possible.

Omega propagation effects are summarized below for easy reference. If you are having difficulty using your Omega receiver or are experiencing unusual position errors, note which stations are being used. Next, visualize the signal paths (always great circles) from the transmitting stations to your receiver, noting the illumination condition on each path (day, night, or transition). Then review the table below to see if any of these conditions affect you. Note that some effects may act in combination. For example, a westerly going signal crossing GREENLAND will be very strongly attenuated due to the combined effects of the orientation of the signal to the earth's magnetic field and low ground conductivity.

OMEGA SIGNAL AVAILABILITY:

Signal availability is the percentage of time that the Omega system is usable by the navigator. This is usually expressed as the percentage of time that a single transmitting station or combination of stations is onair. Exclusive of scheduled annual maintenance, each station is normally on-air greater than 99% of the time. Including off-air periods for maintenance and those off-airs caused by equipment failures, average signal availability for each station is 97%. The expected availability of three stations at any location is 95%.

Each transmitting station must be shut down for extended maintenance once each year. Annual maintenance periods normally last ten days to two weeks, but can be longer for major maintenance projects. These annual maintenance periods are normally scheduled during the months shown below.

A	Norway	August
B	Liberia	February
C	Hawaii	June
D	North Dakota	July
E	La Reunion	September
F	Argentina	March
G	Australia	November
H	Japan	October

Notification of annual maintenance periods is usually made four to six weeks prior to the beginning of the off-air period. Brief off-air periods, usually several hours or less, may be scheduled at other times for maintenance that cannot be deferred until the annual maintenance period. Whenever possible, notification is made of such off-air periods at least several days in advance. See Chapter 5 for information on Omega status reports.

C. OMEGA SIGNAL COVERAGE:

Signal coverage describes the areas of the earth's surface and airspace in which Omega signals are adequate to permit the navigator to determine position to the specified level of accuracy. Because Omega coverage is determined by the propagation characteristics of the signals, and because propagation conditions vary widely over time, Omega coverage cannot be expressed by any single statement or coverage diagram.

The limits of coverage may be described by two parameters. The first parameter is the SIGNAL STRENGTH, which is usually expressed as the SIGNAL TO NOISE RATIO (SNR) As the Omega signal propagates through the waveguide, it gradually attenuates, or loses strength relative to the ambient electrical noise always present in the atmosphere. At some threshold SNR the Omega receiver can no longer distinguish the Omega signal from the electrical noise and that particular signal becomes unusable for navigation. Two SNR thresholds are commonly used to define coverage limits: -20 decibels (dB) and -30 dB. The -20 dB value was established for Omega receivers made before the mid 1970's. Later receivers have proven to be more sensitive and may use signals at the lower SNR value of -30 dB.

The second limiting coverage parameter is MODAL INTERFERENCE, was described in Section A of this chapter. Modal interference exists when the signal phase varies by 20 cec or more from the ideal "Mode 1" phase predictions. Modal interference is always present within 450 n.mi. of the transmitters, and also occurs at long distances from the transmitters, as described.

The coverage boundaries for SNR and modal interference are very irregular. In some areas SNR may be the limiting factor, while in others modal interference may limit coverage. The eight Omega transmitting stations are situated to provide, to the greatest degree possible, worldwide three station coverage above the thresholds of SNR and modal interference.

The accuracy of navigation within signal coverage areas will be affected by the geometry of the signal paths. For a given amount of LOP error, two LOPs which cross at a right angle will have the least fix uncertainty, while two LOPs which are nearly parallel will have the greatest fix uncertainty. This uncertainty is called GEOMETRIC DILLUSION OF PRECISION. or GDOP. As the crossing angle of LOPs increases, the GDOP decreases.

As a general rule, it is expected that at least three Omega stations, with suitable position fixing geometry, will be available 95% of the time in 95% of the world. In planning a flight or voyage, navigators should always refer to Omega coverage diagrams, discussed below, to be sure that sufficient coverage will be available on the planned route, particularly if a station likely to be used is off-air for maintenance. Many automatic receivers are programmed to automatically select an optimum combination of stations which minimizes the modal and long-path interference and GDOP.

Omega coverage diagrams are available in several different formats. (See Chapter 5 for ordering information) The Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) publishes single station coverage diagrams in one volume. These diagrams show -20 dB and -30 dB SNR limits and modal interference limits at 10.2 kHz for each Omega station at 0600 UT and 1800 UT for April to September and October to March.

These diagrams are the easiest to use but are limited to two time periods per year. A more complete set of coverage diagrams is available from the National Technical Information Service in a set of technical reports prepared for the Coast Guard, titled Omega Signal Coverage Prediction Diagrams for 10.2 kHz. Volume II contains individual station diagrams showing SNR contours for 20 and -30 dB and modal interference contours at 0600 UT and 1800 UT for February, May, August, and November. These diagrams are similar to those published by DMAHTC, but are displayed for four times of the year rather than two six month periods. Volume III contains composite coverage diagrams which show coverage for all stations at a given time on a single diagram. Mercator and north and south polar coverage diagrams showing -20 dB and -30 dB limits are shown for 0600 UT and 1800 UT for February, May, August, and November. A separate report shows coverage diagrams for 13.6 kHz in a similar format.

A more versatile coverage diagram is available on electronic media for use with some personal computers. This product is called Omega Automated Composite Coverage Evaluation of System Signals, or Omega ACCESS. ACCESS will display a composite coverage diagram for 10.2 kHz, 13.6 kHz, or both frequencies, for any combination of stations, using either -20 dB SNR or modal interference, or both, for coverage limits. Nighttime modal interference limits can also be shown. Diagrams can be displayed in mercator or polar projections. Great circle tracks can be overlaid the diagrams, and station availability and an index of geometric dilution of precision can be determined at any point. As with other coverage diagrams, ACCESS displays coverage at 0600 and 1800 UT for February, May, August, and November. ACCESS can be run on an IBM PC/XT/AT or compatible computer with PC or MS-DOS version 3.00 or higher, 512K of memory, two floppy disk drives, and a color graphics monitor. ACCESS can be obtained by writing to: Commanding Officer, Navigation Center, 7323 Telegraph Road, Alexandria, VA, 22315-3998.

CHAPTER 5. OMEGA INFORMATION, CHARTS, AND PUBLICATIONS

A. GENERAL. This chapter lists sources for Omega system status information, charts, publications and coverage diagrams. Sources of other technical reports and information of interest to Omega users are also included.

B. THE OMEGA NAVIGATION SYSTEM CENTER.

ONSCEN is the Coast Guard unit responsible for operational control of Omega. ONSCEN is staffed on weekdays between 7:00 AM and 3:30 PM, Eastern Time. During these hours information on Omega, including the current system status, scheduled off-air periods and any navigational warnings in effect, may be obtained by calling (703) 866-3800. At other times a Command Duty Officer (CDO) is on watch and can be contacted by calling the same number; a recorded message will give the name and telephone number of the CDO. Written inquiries may be addressed to:

Commanding Officer
Navigation Center
7323 Telegraph Road
Alexandria, VA
22315-3998

A recorded message giving the current status of Omega is available at any time by calling (703) 313-5906. This recording gives the dates and times of scheduled off-air periods, any navigational warnings in effect due to signal disturbances, and any other important system information. Routine Omega status reports and navigational warnings are also available through the following means:

1. Radio Broadcast: The Department of Commerce, National Bureau of Standards, broadcasts Omega status advisories on radio stations WWV, Fort Collins, Colorado, and WWVH, Kauai, Hawaii, on 2.5, 5, 10, and 15 MHz. WWV also broadcasts on 20 MHz. Omega status advisories are broadcast at 16 minutes past each hour on WWV, and at 47 minutes past each hour on WWVH. These advisories contain dates for scheduled off-airs and any navigational warnings in effect. Because each announcement is limited to 40 seconds, the specific times for each scheduled off-air period may not be given.

2. Notice to Airmen (NOTAM): When alerted by the Coast Guard, the FAA issues NOTAMs to warn of signal disturbances or unscheduled off-air periods. Aviators should consult their local FAA office for details regarding the issuance of Omega NOTAMs.

3. Notice to Mariners: Omega information is disseminated in Notices to Mariners, Local Notices to Mariners, and Broadcast Notices to Mariners. Subscription to the Notice to Mariners can be obtained by writing to DMAHTC at the address given in the following section. Local Notices to Mariners are available by writing to the nearest Coast Guard district office. The Coast Guard district office can also provide information on Broadcast Notices to Mariners from Coast Guard Communications Stations. More information on these and other broadcast navigational warnings can be found in DMAHTC Publication 117, Radio Navigational Aids.

C. DEFENSE MAPPING AGENCY HYDROGRAPHIC/TOPOGRAPHIC CENTER (DMAHTC):

DMAHTC distributes these products:

1. Omega Coverage Diagrams: Single station signal coverage diagrams showing limits of -20 dB SNR, -30 dB SNR and modal interference, for 0600 UT and 1800 UT, April-September and October-March. Stock No. OMPUB224COVDIAG.*

2. Omega Plotting Charts, 7600/7700 series: 1:2,187,400 scale charts covering the entire world.

Overprinted with 10.2 kHz Omega lattice, covering water and land areas. No hydrographic or topographic data shown. Stock Nos. OMEGA7601 through OMEGA7726.*

3. Omega Lattice Tables: Used to construct 10.2 kHz Omega lattice on plotting sheets when Omega overprinted charts are not available. Publication Series No. OMPUB224.*

4. Omega Propagation Correction Tables: Used to correct observed phase readings for predictable variations in propagation. Publication Series No. OMPUB224.*

5. Radio Navigational Aids, Publication 117: Contains information on radionavigation systems worldwide, including Omega. Stock No. RAPUB117.*

6. American Practical Navigator, Volume I: Standard reference text for marine navigation, includes detailed section on Omega. Stock No. NVPUB9V1.* Also available at most nautical chart sales agents. These products are listed in the DMA Catalog of Maps, Charts, and Related Products, Part 2-Hydrographic Products, Volume X, Stock No. CATP2V10.

7. Standard Nautical Charts: Large and small scale charts overprinted with Omega lattice. Includes charts issued by the National Ocean Service These charts are listed in the above catalog, Part2 Hydrographic Products, Volumes I through X, Stock Nos. CATP2V01 through CATP2V10. See also Catalog of Nautical Charts, Numerical Listing of Charts and Publications, Stock No. CATPB1NL; and Catalog of Nautical Charts, Miscellaneous and Special Purpose Navigational Charts, Sheets, and Tables, Stock No. CATPB1NA. These products can be ordered from:

Navigation Information and Services
SMEA, ST D44
Defense Mapping Agency
4600 Sangamore Road
Bethesda, Maryland 20816-5003
(301) 227-3175 or fax to (301) 227-3731

D. NATIONAL OCEAN SERVICE:

NOS distributes General Charts (1:150,000 to 1:600,000) and Sailing Charts (<1:600,000) overprinted with Omega lattice for U.S. coastal waters. These products can be ordered from:

Distribution Branch (N/CG33)
National Ocean Service
Riverdale, Maryland   20737-1199
(301) 436-6990

E. NATIONAL TECHNICAL INFORMATION SERVICE:

NTIS publishes an extensive amount of federally sponsored technical literature relating to

Omega. The most commonly requested publications, inculding the coverage diagrams described in Chapter 4, are listed below. (The number following the report title is the NTIS Accession Number):

1. Omega Signal Coverage Prediction Diagrams for 10.2 kHz:
   Volume I: Technical Approach, ADA 092741
   Volume II: Individual Station Diagrams, ADA 092742
   Volume III: Composite Diagrams, ADA 092743
   Volume IV: Bearing Angle Tables, ADA 092744

2. Specification of the Transmitted Signal of the Omega Navigation System, ADA 137673

3. Omega Propagation Corrections: Background and Computational Approach, ADA 008424

4. 1988 Federal Radionavigation Plan, BD 89163075 These products can be ordered from: National Technical Information Service (NTIS) Springfield, Virginia 22161 (703) 487-4600

F. OTHER SOURCES OF INFORMATION:

1. The International Omega Association, Inc. (IOA): The IOA publishes the BIBLIOGRAPHY OF OMEGA PUBLICATIONS and PROCEEDING OF ANNUAL MEETINGS, containing papers on Omega use, equipment, research and policy. The address is:

International Navigation Association
P.O. Box 2324
Arlington, Virginia 22202-0324

2. The Institute of Navigation (ION): The ION publishes a quarterly journal, NAVIGATION, which periodically contains papers on Omega. The Fall 1986 issue of NAVIGATION, Volume 33, No. 3, was dedicated to Omega and is a good general reference. The address is:

Institute of Navigation
1026 16th Street, N.W., Suite 104
Washington, DC 20036
(202) 783-4121

GLOSSARY OF TERMS:

ANTIPODE: The point on the globe directly opposite the transmitter.

BASELINE: The great circle between two transmitting stations.

BASELINE EXTENSION: The continuation of the baseline beyond transmitting stations at both ends of the baseline. In the hyperbolic mode the gradient or rate of phase change rapidly decreases in the region of the baseline extension, greatly increasing position errors.

CENTICYCLE: (CEC) One hundredth of a cycle.

CENTILANE: (CEL) One hundredth of a lane; numerically equal to one cec at 10.2 kHz.

CYCLE: One complete oscillation of a radio wave, starting from zero amplitude, reaching a positive peak, passing through zero amplitude to reach a negative peak, then returning to zero amplitude again. One complete wavelength is one cycle.

DESELECTION: A receiver input which prevents use of signals from a specified station or stations. Stations are usually deselected when modal or long-path interference is expected in the area of operation, when the signal path is affected by a polar cap disturbance, or when the station is expected to be unreliable for any reason. Some receivers are programmed to automatically deselect stations under certain criteria.

DIFFERENTIAL OMEGA: A medium range accuracy enhancement technique using the real time transmission of local phase corrections.

FOCUSING: An increase in signal strength at the antipode of the transmitter, due to the convergence of the signal in an increasingly smaller area of the waveguide.

GEOMAGNETIC EQUATOR: The equator of the earth's magnetic field, lying between the north and south magnetic poles.

GEOMAGNETIC DILLUSION OF PRECISION (GDOP): The degree of uncertainty of a position fix with respect to the crossing angles of the LOPs.

HYPERBOLA: A curve that intersects all points which have a constant difference in distance from two fixed points or foci.

INITIALIZATION: Entering values for specified parameters in a receiver before starting a flight or voyage. Usually includes present position, date, time; may also include lane numbers and station selection or deselection.

IONOSPHERE: An atmospheric layer of electrically charged particles which form the upper boundary of the waveguide in which Omega signals propagate.

KILOHERTZ: 1,000 hertz or cycles per second.

LANE: The area bounded by contours of zero phase (direct ranging mode) or zero phase difference (hyperbolic mode).

LATTICE: The grid formed by families of hyperbolic LOPs from two or more station pairs.

LATTICE TABLE: A table containing data used to construct an Omega lattice on a plotting sheet. Used when Omega charts are not available.

MODAL INTERFERENCE: Phase deviations caused by modes with different phase velocities, on a given frequency, interfering with each other. Omega signals are unreliable in areas of modal interference.

MODE: One of an infinite number of electromagnetic wave patterns on a given frequency. Omega propagation corrections and position computations are based on Mode 1 signals which are the dominant mode at distances greater than 450 n.mi. from a transmitter.

NAUTICAL MILE: (n.mi.): 6,080 feet; 1.1516 statute miles; 1.852 kilometers.

PATH: The great circle between a transmitter and receiver.

POLAR CAP DISTURBANCE (PCD): A deviation in the phase of signals whose paths cross the polar regions above 60 degrees north or south latitude. Occurs when a solar flare emits showers of protons which cause a sudden, sustained depression of the reflective boundary of the ionosphere. Previously called a polar cap absorption event or PCA.

PROPAGATION: The transfer of electromagnetic energy through a medium.

PROPAGATION CORRECTION: A correction applied to observed phase readings to account for predictable variations from charted phase values.

RATE AIDING: A technique of advancing phase measurements, using speed and heading inputs, to give the effect of simultaneous measurements. Also helps to maintain lane count during maneuvers.

SUDDEN IONOSPHERIC DISTURBANCE: A deviation in the phase of signals whose paths are in daylight. Occurs when a solar flare emits bursts of x-rays which cause a sudden, short term depression of the reflective boundary of the ionosphere.

TERMINATOR: The great circle boundary between the day and night hemispheres of the earth

TRANSITION: The crossing of a signal path by the terminator. Can cause abrupt phase changes.
UTC: Abbreviation for Coordinated Universal Time; commonly given as UT. The same as GMT and Zulu (Z) time.